CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER - 117

March 28, 1981

1. Name of fault.

Greenville fault. (includes southeast end of Marsh Creek fault).

2. Location.

Alameda, Contra Costa, and Santa Clara Counties; Tassajara, Byron Hot Springs, Altamont, Midway, Cedar Mtn., and Eylar Mtn. quadrangles (Figure 1).

3. Purpose of evaluation.

Part of 10-year fault-evaluation program under the Alquist-Priolo Special Studies Zone Act (Hart, 1980). Minor fault rupture occurred along the northeast margin of Livermore Valley following the January 1980 earthquakes.

4. References.

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5. <u>Review of available data.</u>

Because of the press of time in completing this report, this review necessarily is brief, although an attempt is made to identify the principal references on the Greenville fault.

The Greenville fault envisioned in this study is a northwest-trending zone of recent, right-lateral, strike-slip faults that extend for 30 miles (46km) from the Tassajara quadrangle to the Eylar Mtn. quadrangle. In addition, the southeast 4-mile (6km) segment of the Mt. Diablo fault (Marsh Creek fault of Brabb, et al, 1971) is included with the Greenville fault for convenience. The zone of faults mapped in this study is based largely on geomorphic features and the ground rupture following the January 1980 earthquakes (see Item 6 below and Figures 5A to 5F).

Geologically, the Greenville fault is an important structural element that separates contrasting rock units along its entire length and apparently interconnects with other north to northwest-trending faults to the northwest and south (Rodgers, 1966; Brabb, et al, 1971; Cotton, 1972; Hanna and Brabb, 1979; Dibblee, 1980a). Figure 2 shows the Greenville fault of this study (in red) and some of the above relationships. As can be seen on Figure 2, a west-trending zone of serpentinite (purple) apparently is offset about 5 miles in a right-lateral sense. Comparable offsets are also suggested by the magnetic anomalies shown by Hanna and Brabb (1979) and geologic units shown by Dibblee (1980a,b,c,d).

The Livermore Valley segment of the Greenville fault was mapped and named by Huey (1948). Huey does not show the fault to extend to the southeast beyond the Livermore Valley (Fig. 3). This segment originally was mapped as part of the Riggs Canyon fault by Vickery (1925). Detailed mapping by Colburn (1961) shows that the Greenville fault is complex and to split into several strands to the northwest, all of which are considered to be part of his Mount Diablo fault. Part of Colburn's work is published in the Geologic Society of Sacramento (1964, map).

Herd (1977) remapped the Greenville fault and shows it to extend southeastward across the Altamont quadrangle. Herd (p. 13) describes the fault as a "wide zone of en echelon fault breaks" that separate the Livermore Valley from the Altamont Hills. He states that this segment of the Greenville fault is nowhere well-exposed and that the faults mapped are based principally on geomorphic evidence. Because similar mapping techniques were used, his mapped traces are very similar to those mapped in this study. Moreover, several of his traces coincided with the ground rupture and cracks produced following the January 1980 Livermore Valley earthquakes. The location of Herd's faults and the 1980 fracture zones are shown on a map by Bonilla, et al (1980), reproduced herein a Figure 4. Hart, et al (1980~~b~~a) also shows the locations of fault rupture, and this report is included as appendix A.

Regarding the evidence for recency of movement along the fault zone in the Altamont quadrangle, Herd has the following to say: "North of the Las

Positas fault zone, unit 2 alluvium is displaced by faults in the Greenville fault zone. The breaks form two prominent northeast- and southwest-facing scarps in the unit 2 alluvium [late Pleistocene] north of Interstate Highway 580, but do not cut recent flood-plain alluvium. Frick Lake, an intermittent lake in sec. 25, T. 2 S., R. 2 E., lies in a graben bounded by two of the faults. South of the Las Positas fault zone, Neroly and older rocks are offset by the Greenville fault zone; the Livermore Gravels and younger alluvium are not." Dibblee disagrees with the last statement and shows the fault to offset both Livermore Gravels and Pleistocene older alluvium.

Regarding the evidence for right slip, Herd states: "In the map area, there is little direct evidence for right-lateral strike-slip motion along the Greenville fault zone except for horizontal slickensides in an outcrop of a fault in the Greenville fault zone along the tracks of the Western Pacific Railroad above Altamont Creek in the southeast corner of sec. 25, T. 2 S., R. 2 E. There, in the headwall of a landslide in the Cierbo Sandstone, polished horizontal slickensides on the surface of the block east of the fault have been exposed by the fall of the west block. The fault is nearly vertical and strikes N.40°W. Continuation of the fault to the northwest is unclear because it is within the Cierbo Sandstone and has not been mapped." [This writer does identify evidence for right-lateral slip, although it is subtle.]

Others have mapped parts of the Greenville fault, the most important of which is Dibblee (1980a,b,c,d). Dibblee shows the fault to be a complex zone of faults extending northwest from the Midway quadrangle through the Tassajara quadrangle. With few exceptions his principal traces closely match the traces mapped in this study (Fig. 5A,B,C,D) southeast of the

Morgan Territory Road (Tassajara quadrangle). To the northwest of that road his Marsh Creek fault is similar to the recent faults mapped for this study (Fig. 5A). Dibblee did not extend the Marsh Creek fault northwestward, as do Colburn (1961) and Brabb, et al (1971). Rather, he maps it to the west, similar to the Morgan Territory fault of Brabb, et al. There is no evidence presented by Dibblee or other workers that shows the Greenville fault to offset Quaternary units anywhere except in the Altamont quadrangle.

The southern segment of the Greenville fault, in the Cedar Mtn. and Eylar Mtn. quadrangles, has not been mapped in detail. Cotton (1972) did map the area at a reconnaissance scale (1:62,500) and shows the fault to be an important and continuous feature. However, the fault's location is approximate and based on the interpretation of aerial photos. Cotton does not name the fault and shows it to merge with or to be truncated by the Tesla fault of Huey (1948) on the north (see Fig. 3). Soliman (1965) and Crawford (1976) also mapped the Eylar Mtn. quadrangle, but only identify that segment of the fault that truncates the serpentinite mass near the west margin of the quadrangle.

Others who have mapped the Greenville and related faults include Clark (1935), Hansen (1966), and Ford and Hills (1974). The first two references are small scale maps; the latter is similar to Huey (1948). There are many other faults mapped to the east and west of the Greenville fault, but none of them appear to be active with the exception of the Las Positas fault of Herd (1977; see FER - 112).

From the data reviewed, it is apparent that various geologists do not agree as to the location of the fault in most places and frequently use conflicting nomenclature. This disagreement is greatest in the Tassajara quadrangle where the fault complex splits into several branches. With the exception of the Altamont quadrangle, where recent geomorphic features suggest the recency of faulting and late Pleistocene and Holocene units are shown to be faulted (Herd, 1977; Dibblee, 1980d), there is no evidence presented by other geologists that late Quaternary units are faulted within the study area.

The minor fault-rupture that occurred in association with the 1980 earthquakes extends discontinuously northwest from Highway I-580 almost to Contra Costa County (Fig. 4; App. A), partly as sudden rupture and partly as after-slip. Suprisingly, no ground rupture was found along the Marsh Creek fault segment, even though it coincides with the main earthquake of January 24 and lies along a well-defined zone of aftershocks (see item 7, below).

6. Interpretation of aerial photographs; field mapping.

Following the January 24 and 26 Livermore earthquakes, staff from CDMG, including this writer, where immediately dispatched to check for ground rupture. Periodic field checking and mapping of cracks continued until early April. The results of this work are summarized by Hart, et al (1980; included herein as Appendix A) and Bedrossian, et al (1980). Results of this work shows that ground rupture was minor and discontinuous, extending over a length of less than 7km (4 mi.) north of Highway I-580 (Fig. 5B,5C, and App. A). All of the offsets measured were consistent with right-lateral, strike-slip movement, although downhill movements caused local dip-slip offsets in soil (max. 12 cm). A maximum of 2-3 cm of right-lateral slip was observed by CDMG, although 7cm was reported by Al Ridley (Seeley, 1980, p. 8). Some of the strike-slip movement measured continued as after-slip at least until April 1980 (App. A and Fig. 4). Disconcertingly, fault rupture occurred on 3 or 4 strands in a zone possibly 600-700 m wide.

It is not known if this surface fault-rupture event is typical or if larger events can occur. However, judging from the nature of the subtle geomorphic features associated with the rupture, the rate of slip on this segment of the Greenville fault is low compared to the Hayward or San Andreas faults.

Although fault rupture was minor and distributive, the crack zones observed align~~s~~ with well-defined geomorphic features (scarps, sidehill benches, offset drainages) and tonal lineaments, identifiable on aerial photos (Fig. 5B, 5C). Many of these features were mapped by Herd (19~~80~~77) prior to the 1980 event, demonstrating the predictability of ground rupture locations in the northwestern part of the Altamont quadrangle (Fig. 4). Comparable mapping of recent fault-related features had not been attempted in the Byron Hot Springs quadrangle, although such features exist.

Armed with the knowledge that active, albeit minor, faulting can be predicted with reasonable confidence a careful stereoscopic interpretation of aerial photographs (USGS, 1974; USDA, 1940) was made for other segments of the Greenville and Marsh Creek faults for evidence of recent faulting. Surprisingly, evidence of systematic recent-strike faulting could be traced (somewhat discontinuously) from the Tassajara quadrangle to the eastern margin of the Eylar Mtn. quadrangle. The nature of this evidence is plotted on Figures 5A to 5F and is summarized below from north to south.

<u>Marsh Creek fault segment (Fig. 5A).</u> This fault segment is defined mainly by linear troughs, drainages and scarps. Evidence of recency is suggested by drainages that deflect right-laterally, especially in sections 31 and 32. Evidence for recency decreases to the northwest and the fault

cannot be traced north of section 24. This fault segment coincides well with the Marsh Creek fault of Dibblee (1980a), who also could not map the fault north of section 24. There are no recent alluvial units to demonstrate Holocene activity, but the fault lies along the aftershock zone following the January 1980 earthquakes.

Tassajara and Byron Hot Springs segment (Fig. 5A, 5B). Northwest of Vasco Road, this fault can be traced mainly as a zone of sidehill benches, tonal features and subtly deflected drainages. Ground-rupture in 1980 (section 15) apparently was partly obscured by downhill movement. Left-stepping cracks were reported in 2 or 3 places, however, verifying minor right-slip displacement on this fault. Also, right-lateral offset of about 2cm was measured in two places on Vasco Road. To the southeast of Vasco Road the southwest trace appears to be the main active fault. The northeast trace is clearly a fault, but it only had extensional cracks developed in 1980. Dibblee (1980b) only maps the southwest trace, which closely follows the geomorphic features mapped herein. The junction with the Marsh Creek fault is somewhat vague and is no doubt complex, as suggested by the change in fault trend between Morgan Territory Road and the county boundary.

Livermore Valley segment (Fig. 5C). This segment consists of several strands that define a complex, linear basin (graben) north of Highway I-580. As indicated by Frick Lake, a closed depression, and associated linear scarps, the northeastern side of the basin appears to be the most active. Most of the 1980 faulting was concentrated along this eastern zone. South of Highway I-580, the Greenville fault is a wide zone of short faults, associated with deflected drainages and closed depressions. The principal active fault appears to be on the east, as that is where the fault features are best defined. Nonetheless, the zone south of I-580 appears to be an incipient graben within which there is distributive deformation. The traces mapped are similar to Herd (1977) and Dibblee (1980c), but differ in detail.

Arroyo Seco segment (Fig. 5C). The northern part of this segment is well-defined by linear scarps, tonal features along a large shutter ridge, and deflected drainages. Between Cross Road and Tesla Road, the Greenville fault is somewhat difficult to follow. However, a zone of aligned benches, deflected drainages and linear tonal features strongly suggest the location of several fault strands, even in the massive landslide near Tesla Road. South of Tesla Road, the main fault trace is well-marked by a linear drainage, benches and a deflected drainages. There is no firm evidence of Holocene movement on the Arroyo Seco segment, although the deflected drainages indicate repeated late Quaternary offset and the sidehill benches suggest probable movement during the Holocene. The interpretation on Fig. 4C is similar to Herd (1977), although he does not map the features in detail along this segment and does not consider this segment to be active. Dibblee's (1980c) faults are similar, but they differ in detail from this writers.

Corral Hollow segment (Fig. 5D, 5E). The northwest part of this segment is extremely well defined by very linear sidehill benches and deflected drainages, which suggest considerable late Quaternary (Holocene ?) displacement. The Greenville fault can be mapped southeastward through most of section 12. However, several minor drainages in sections 2 and 12 do not appear to be offset. It is uncertain whether this reflects the high rate of erosion and lateral-spreading of the ridges or the absence of Holocene faulting.

Arroyo Mocho segment (Fig. 5E & 5F). Although this segment of the Greenville fault can be located with a fair degree of confidence, the fault is locally obscured by massive landsliding and lateral spreading of the ridges. According to Cotton (1972), who also mapped this fault using aerial photos, the fault passes entirely through Franciscan terrane, much of it melange.

Evidence for recent displacement appears to diminish southward and clear evidence of recent faulting cannot be identified beyond the east boundary of the Eylar Mtn. quadrangle. Many right-laterally offset drainages and sidehill benches exist locally along this fault segments, but intervening sections are crossed by drainages that do not appear to be offset. Again, this offset may be due to a high rate of erosion and large-scale downhill movements in the Franciscan melange. Where serpentinite is offset in the southern part of the Cedar Mtn. quadrangle, the fault is very well defined and evidence of recent right-slip is convincing, although Holocene activity cannot be absolutely demonstrated. This fault strand can be traced for 3 km into the Eylar Mtn. quadrangle, where a large landslide apparently obscures the trace, in part. Another serpentinite body, near the east margin of the Eylar Mtn. quadrangle, apparently is truncated by the Greenville fault, whose recency is indicated by deflected drainages and sidehill benches.

7. Seismicity.

Based on the earthquakes recorded prior to the January 1980 Livermore earthquakes, the Greenville fault would have been classified as "probably seismically active" by Ellsworth and Marks (1980, p. 16). Their epicenters are shown on Figure 6. Figure 7 clearly shows the relationship of a 30 km-long aftershock zone to the Greenville and Marsh Creek faults. The seismic events of January and February are discussed in detail by Cockerham, et al (1980), who state that the fault plane solutions suggest that "focal mechanisms for the main shock and most aftershocks consist predominantly of dextral strike-slip movement on fault-planes striking northwest."

The epicenters shown in Figure 6 would seem to suggest that the Greenville fault is seismically active in the Cedar Mtn and probably the Eylar Mtn quadrangles. However, this area is not well-covered by seismic stations.

8. Conclusions.

Based on geomorphic evidence alone (Figures 5A to 5F), it is concluded that the Greenville fault is a well-defined, more or less continuous fault that extends for 33 miles (52-km) from the Tassajara quadrangle to the eastern edge of the Eylar Mtn quadrangle. The fault cannot be traced with any degree of confidence, and is not well-defined, to the north or south of there.

Evidence for Holocene activity is permissive, but not mandatory, except for the Livermore Valley segment where sharp tonal lineaments in Holocene alluvium align with well-defined scarps and other recent geomorphic features. However, ground rupture and the seismicity associated with the 1980 earthquakes clearly reveal that the northern segments of the Greenville and Marsh Creek faults are active (at least at depth).

The Arroyo Seco segment is only moderately well-defined, but is identified by features that indicate late Pleistocene or Holocene right-lateral slip of large scale. Moreover, the fault is at least seismically active at depth.

The Corral Hollow segment and parts of the Arroyo Mocho segment are suspected of being active based on the existence of well-defined sidehill benches, which tend to be short-lived features, and the abundance of right laterally deflected drainages on-trend with the linear geomorphic features. The evidence for recency appears to diminish somewhat to the south. However, there are no Holocene alluvial units or surfaces present across the southern part of the Greenville fault to absolutely test Holocene activity. Scattered seismicity in the Cedar Mtn. and Eylar Mtn quadrangles suggest that this segment of the Greenville fault is active at depth.

9. Recommendations.

The Livermore Valley and Byron Hot Springs segments of the Greenville fault should be zoned for Special Studies as they clearly meet the criteria of "sufficiently active and well-defined" (Hart, 1980, p. 5-6). Although the zone is wide, individual faults within it are well-defined and mappable.

The Greenville and Marsh Creek faults are fairly well defined in the Tassajara quadrangle and are at least seismically active. It is recommended that these segments be zoned.

The Arroyo Seco segment is reasonably well-defined. It has surface evidence suggestive of Holocene activity and is known to be seismically active and therefore should be zoned.

The Corral Hollow segment is a very well-defined continuation of the Arroyo Seco segment and it too is recommend for zoning.

The Arroyo Mocho segment, as a whole, is well-defined and in several places it exhibits significant right-lateral displacement that is strongly suggestive of Holocene activity. Zoning is recommended, although the area is remote and not subject to near-future development.

It is not recommended that the minor faults and linear features away from the main fault be zoned.

Zoning should be based primarity on Figures 5A to 5F, using the work of Bonilla, et al (1980) and Herd (1977) for the Livermore Valley and Byron Hot Springs segments.

10. Report prepared by: EARL W. HART, March 28, 1981

Earl W. Hart

Figure 1 (FER-117). Location of the Greenville fault, FER study area, and 7.5' quadrangles (1--Tassajara; 2--Byron Hot springs; 3--Altamont; 4--Midway; 5--Cedar Mtn.; 6--Eylar Mtn.)

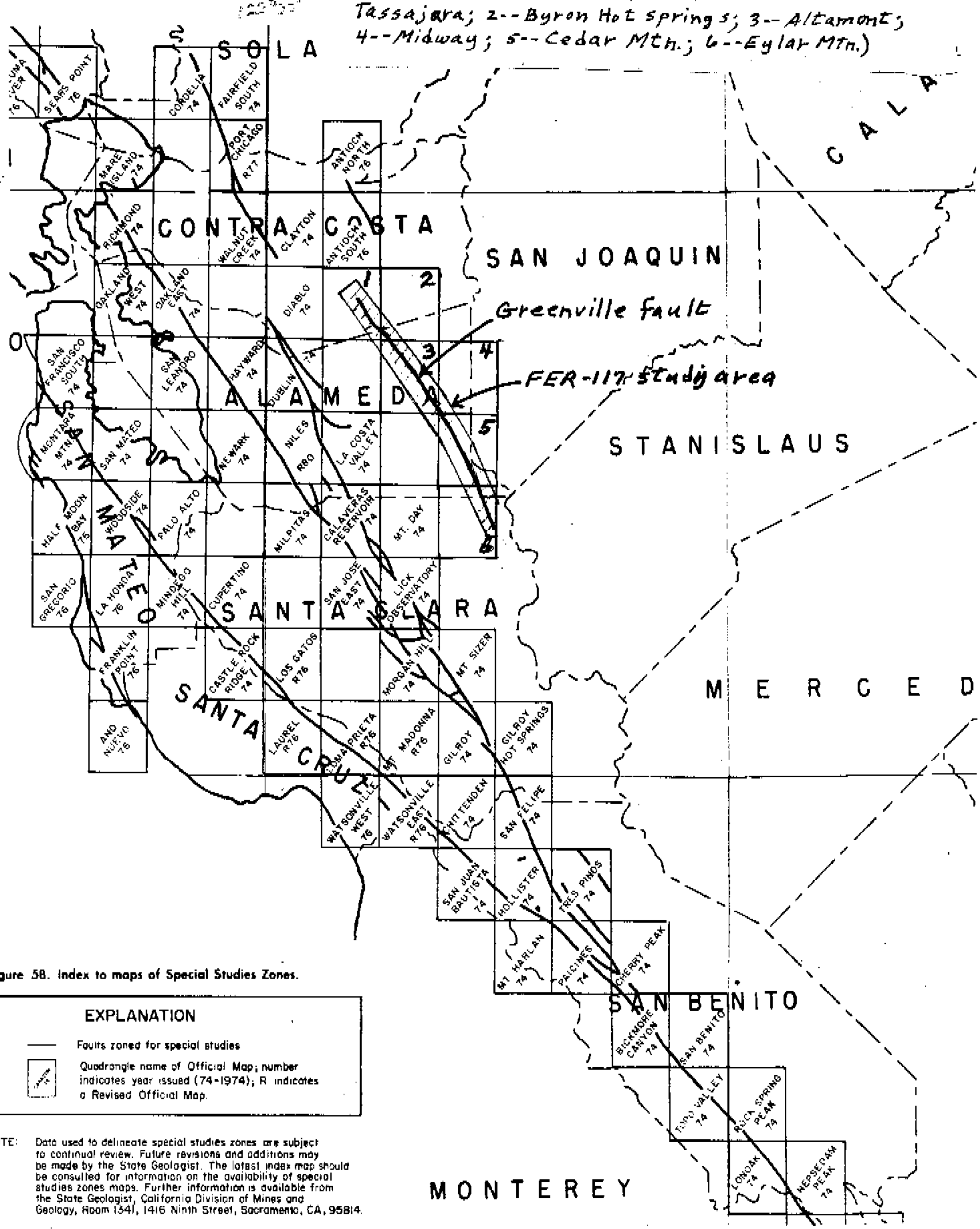


Figure 58. Index to maps of Special Studies Zones.

NOTE: Data used to delineate special studies zones are subject to continual review. Future revisions and additions may be made by the State Geologist. The latest index map should be consulted for information on the availability of special studies zones maps. Further information is available from the State Geologist, California Division of Mines and Geology, Room 1341, 1416 Ninth Street, Sacramento, CA, 95814.

Scale 1:1,000,000
1 inch equals approximately 16 miles

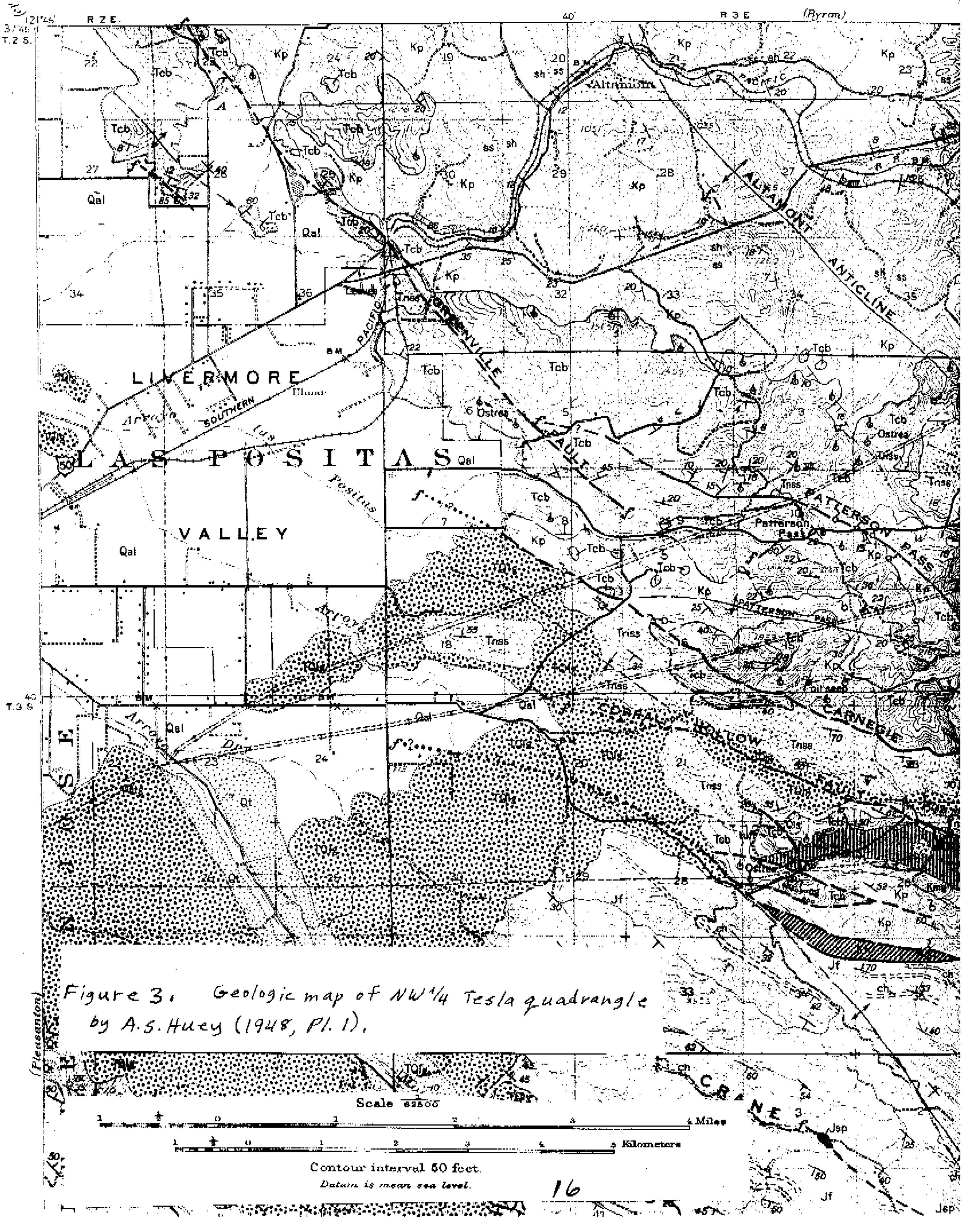
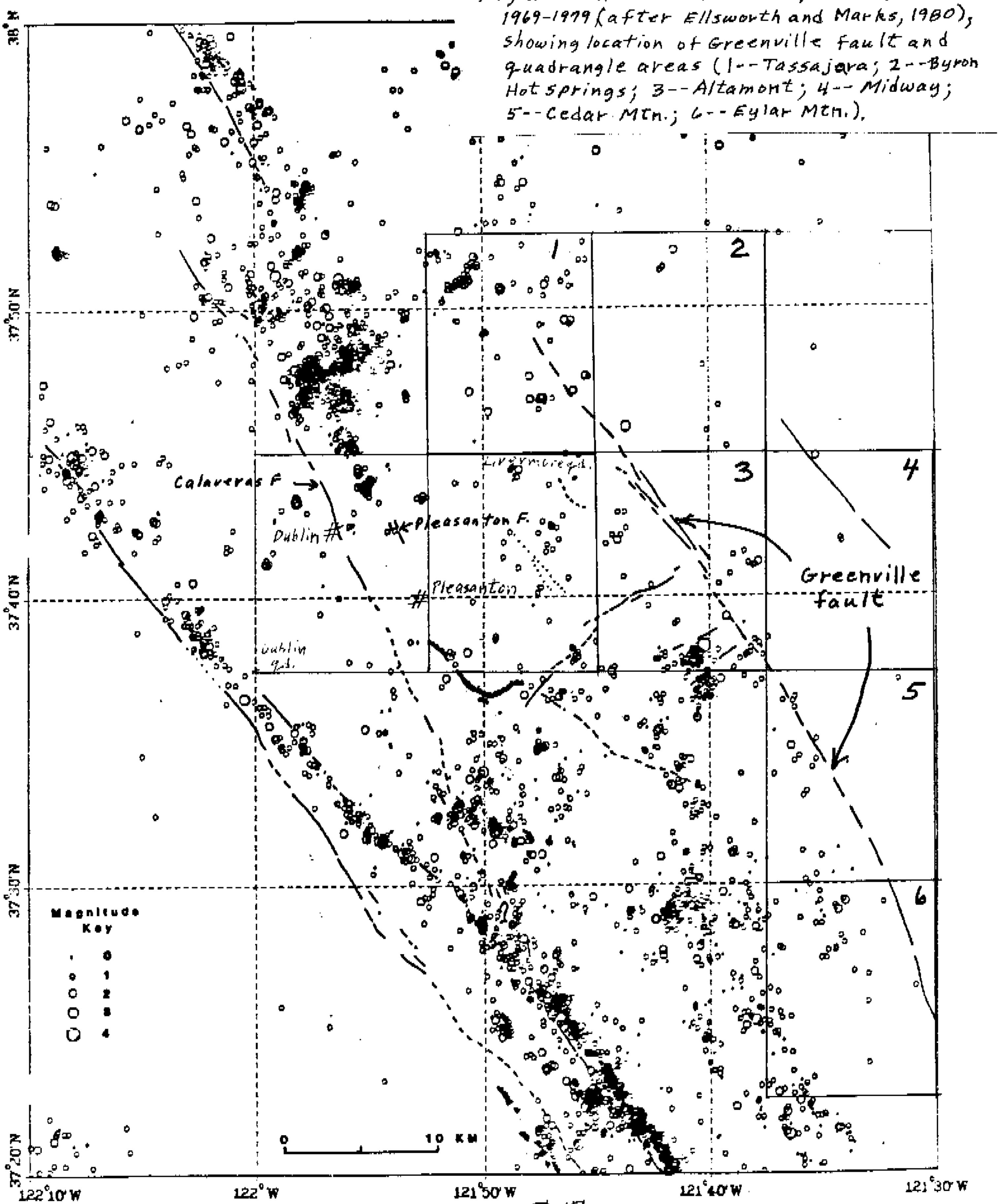


Figure 3. Geologic map of NW 1/4 Tesla quadrangle by A.S. Huey (1948, Pl. 1).

LIVERMORE REGION STUDY AREA

1969 – 1979

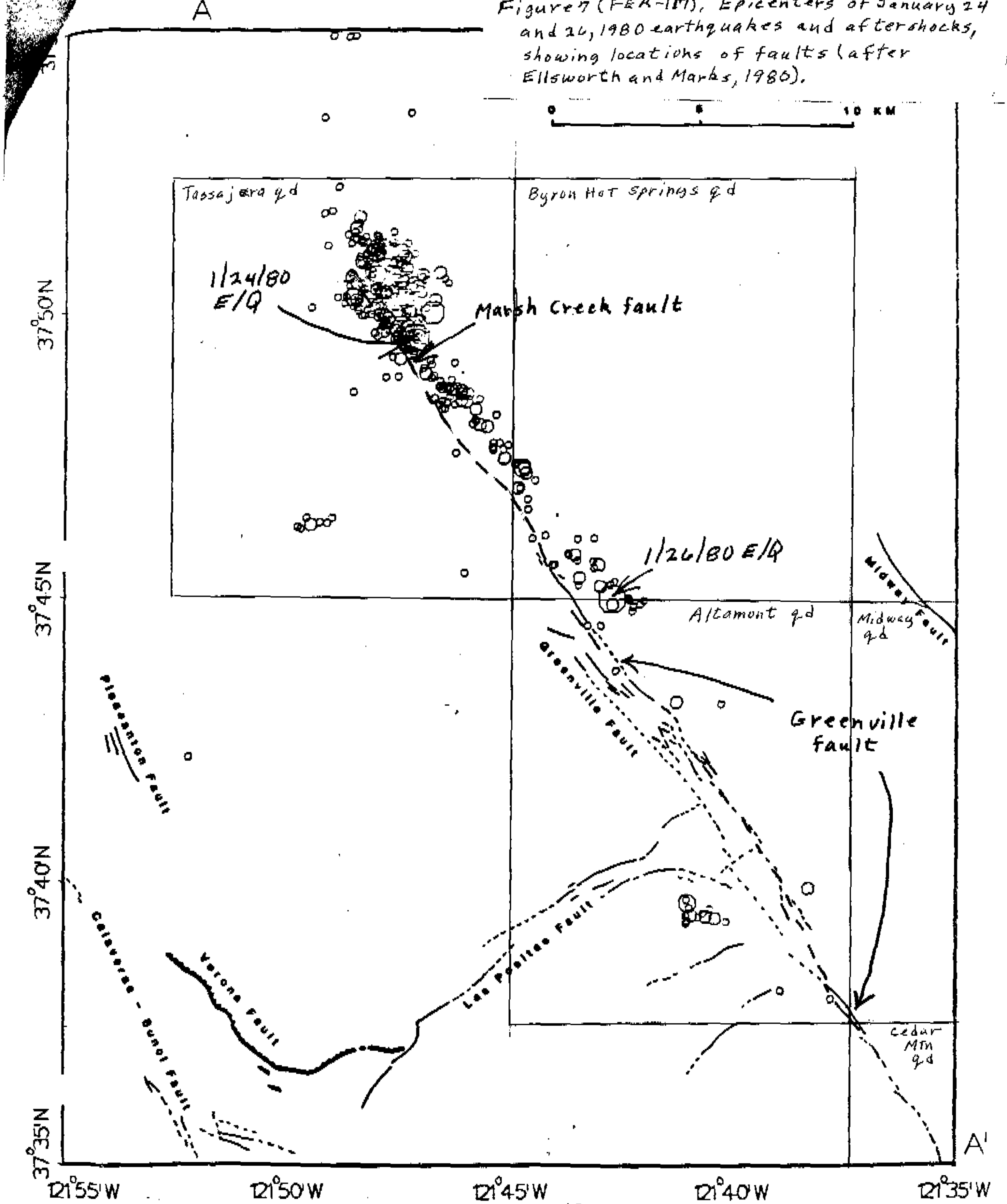
Figure 6 (FER-117). Earthquake epicenters 1969-1979 (after Ellsworth and Marks, 1980), showing location of Greenville fault and quadrangle areas (1--Tassajara; 2--Byron Hot springs; 3--Altamont; 4--Midway; 5--Cedar Mtn.; 6--Eylar Mtn.).



LIVERMORE VALLEY EARTHQUAKES

JAN 24 – FEB 26 1980

Figure 7 (FER-117). Epicenters of January 24 and 26, 1980 earthquakes and aftershocks, showing locations of faults (after Ellsworth and Marks, 1980).



Appendix A
(FER-117)

CALIFORNIA DIVISION OF MINES AND GEOLOGY

Field Trip Guide, April 12, 1980

Greenville Fault, East Livermore Valley
Prepared by Earl Hart

Field trip leaders: Earl Hart, CDMG
Trinda Bedrossian, CDMG
Al Ridley, Woodward-Clyde Consultants

The Livermore Valley 5.5M earthquake of January 24, 1980 (11:05 AM) was centered north of the Livermore Valley near the Mt. Diablo fault of Colburn (1961). This was followed on January 26 by a 5.2M earthquake near Frick Lake, on the Greenville fault.

Both earthquakes, which were of shallow focus, did considerable damage in the Livermore Valley and east Mt. Diablo areas. Aftershocks clearly identified the Greenville and Mt. Diablo faults as active. However, no fault rupture was observed along the Mt. Diablo fault and only minor, discontinuous rupture was observed on several strands of the Greenville fault. Preliminary first-motion studies indicate right-lateral subsurface displacement.

Structural Setting, Nomenclature

The Greenville fault forms the local boundary between the Livermore Valley on the west and the Altamont Hills on the east. Its general relationship to other faults is summarized by Rogers (1966). Further to the northwest, the Altamont Hills and Mt. Diablo have been thrust obliquely southward over strata along the northeast margin of Livermore Valley.

The Greenville fault was first mapped by Vickery (1925) as the Riggs Canyon fault. Huey (1948) mapped the fault in detail and was the first to apply the name "Greenville" (a local name, apparently not on topo maps). Huey and Vickery both show the fault to merge to the southeast with the more easterly-trending Patterson Pass, Carnegie, Corral Hollow and Tesla reverse faults and associated folds. Based on geomorphic interpretations, Herd (1977) remapped the Greenville fault, showing it to be a broad zone of late Quaternary faults. Herd considers the fault to be right-lateral, but does not provide specific documentation. Such documentation is provided on the attached (Figure 1) as indicated by geomorphic features and the January 1980 ground rupture observations. To the northeast, the Greenville fault merges with the Morgan Territory and Riggs Canyon Branches of the Mt. Diablo fault of Colburn (1961; 1964). Other fault nomenclature and interpretations have been made by Clark (1935) and Brabb, et al (1971). It is generally assumed that the Morgan Territory fault, which lies on trend with the Greenville fault, was the source of the January 24 earthquake. However, the Riggs Canyon fault, an important northeast-dipping reverse fault, may have produced the earthquake.

* The above magnitudes are from the USGS: UC Berkeley readings were 5.2M and 5.8M for the January 24 and 26 earthquakes, respectively. The faults and earthquake epicenters are shown on Figure 1 of Bedrossian, et al (1980), who summarized the Livermore Valley earthquakes and effects based on preliminary data. Users of this guide are referred to that report for background and orientation.

The attached map of the Greenville fault is based on recent mapping of ground rupture and the interpretation of aerial photos (Figure 1). It is similar to the Quaternary fault traces of Herd (1977) in the Altamont quadrangle but differs from the map of Brabb, et al (1971) in the Byron Hot Springs quadrangle. The west and east traces of the Greenville fault coincide with the boundaries of a partially closed topographic subbasin, referred to as the Greenville subbasin herein. This subbasin is believed to be formed by complex extensional openings along sets of right-stepping faults. Apparently, the most active part of the subbasin is Frick Lake and its associated graben which formed between the main (east) trace and a central trace (see model, Figure 2 and Stop 3). Using the model for extensional opening between right-stepping right-slip faults helps predict the location of active faults. The active trace of the Greenville fault has not been identified south of Greenville Road. South of its inferred intersection with the Las Positas fault, Herd (1977) does not believe there is evidence for even Quaternary activity on the Greenville fault. Indeed, the fault may give way to other easterly-trending faults (Huey, 1948).

Ground Rupture

Following the 1/24/80 earthquake, geologists from CDMG were dispatched to the field to observe and measure fault rupture as soon as possible, in order to distinguish earthquake-associated fault-rupture from the inevitable afterslip. Also, CDMG geologists, responsible for establishing regulatory zones for active faults under the Alquist-Priolo Special Studies Zones Act, needed to know the locations of the active fault traces before the evidence was destroyed by erosion or man. The extent and nature of fault rupture is summarized on the attached map, along with photo interpretations of the recent fault traces. Other geologists from Woodward-Clyde Consultants, USGS, UC Berkeley, and other organizations also responded to this earthquake and have gathered a great deal of data.

Fault rupture was discontinuous over a distance of about 5 km and occurred on three separate traces. Careful review of low- sun angle (USGS, 1974) and black and white (USDA, 1940) aerial photos revealed evidence (mostly subtle) for recent faulting that coincided with most of the ground rupture. Other recent fault traces also are inferred along which fault rupture did not occur (Figure 1). Systematic right-lateral slip to a maximum of 2cm was observed in several places, including at Vasco and Laughlin Roads (Stops 2 and 5). Some of the slip occurred during the earthquake of January 24 (Vasco Road) and some commenced after the earthquake and continued for about a month (Laughlin Road). Afterslip was studied in detail by Woodward-Clyde geologists and is summarized by Schwartz, et al. (1980 -- abstract attached). Left-stepping cracks were observed locally in the soil, but most of the cracks merely showed extensional opening to 3 or 4 cm. These cracks were obliterated by the heavy February rains. Some downhill movement due to shaking apparently occurred on the hill slopes and overprinted the fault rupture with landslide and pull-apart features, resulting in grabens and scarps with vertical offsets to 12 cm. Very minor faulting also may have occurred along a western trace of the Greenville fault, as suggested by cracks in Laughlin Road (Stop 4).

Since passage of the Alquist-Priolo Act, it has become increasingly clear that evaluating faults for recency of activity and fault-rupture hazard is a sensitive and difficult task. Even determining which faults to zone has its problems. Present zoning criteria are (1) evidence of Holocene faulting and (2) ability to locate the fault in the field with some degree of confidence. CDMG's zoning program, the Alquist-Priolo Act, and guidelines for evaluating for fault rupture are discussed by Hart

(1977; being revised 1980). The Greenville fault clearly meets CDMG's zoning criteria where recent ground rupture has occurred, but it is uncertain whether this fault would have been recognized as Holocene active had the January earthquakes not occurred. It is also uncertain how much of the fault should be zoned northwest and southeast of the rupture zone. It is important to note that some active faults are only slightly active (low rate of slip and are difficult to distinguish from inactive (pre-Holocene) faults.

FIELD TRIP ITINERARY

<u>Stop 1.</u> Field trip meets on Altamont (frontage) Road just west of the Greenville overpass, Highway I-580. Settlement of the fill of the approaches to the Greenville overpass (as much as 18 cm on the west side of the eastbound lanes) and cracks in the asphalt pavement of Altamont road have led some people to believe that this damage was due to fault rupture. Moreover, the overpass bridge is on trend with a recent fault (Herd, 1977; Figure 1). However, no horizontal or vertical slip was observable in this vicinity. Settlement of the fill approaches, relative to the overpass bridge, clearly was due to shaking. Previous settlement, recorded by Caltrans prior to the January 1980 earthquakes, suggests compressible, soft or deep alluvium in the vicinity of the overpass. Minor subsidence along Altamont Road also is suggested by the new cracks formed. If so, this would fit the concept of a distributive faulting and resultant extension and subsidence of the Greenville subbasin (Figure 1). A triangulation site, located just south of I-580 across the east trace of the Greenville fault, has shown no systematic strain since 1964. Minor level changes have been measured across the fault zone since 1964 and since the January earthquakes, but the meaning of these changes is uncertain.

1-3 mm of right-lateral slip observed on crack in Altamont Rd at Greenville Rd on 4/12/80; probably due to fault slip – EWH

<u>Stop 2.</u> Laughlin Road at foot of hills. Left-stepping en echelon (figure 4) cracks in asphalt pavement identify a segment of the Greenville fault that was active following the 5.5M Livermore Valley earthquake of January 24, 1980. These cracks coincide with a trace mapped by Huey (1948) and Herd (1977). The cracks were not noted 3 hours after the earthquake but appeared by January 25, when 2 mm of right-lateral slip was measured. This cracking preceded the 5.2M earthquake of January 26, which was centered near Frick Lake. Colored marks on pavement were painted by Woodward-Clyde Consultants to monitor afterslip. Reobservation of the cracks showed 5 mm of right-slip on January 30 and 7 mm on February 27, an additional 1-2 mm of slip was reported on April 3 (D. Schwartz, 4/4/80). Thus, most, if not all, of the slip has occurred as afterslip - either by creep or incremetally. The zone of cracks could be traced northwestward in the soil prior to the heavy rains of February. 1000 feet southeast of Stop 2 is a broad zone of N to N30°E - trending cracks in the pavement that suggest right-lateral slip of 1.7 cm and 0.3 cm vertical slip (eastside down). Note the progressive right-lateral offset of the paint marks, demon-

strating afterslip.

Stop 3. Laughlin Road south of Frick Lake. Frick Lake is a closed depression (sag pond) formed by recent subsidence, presumably caused by right lateral extension between two right-stepping faults (see diagram for model, Figure 2). The east (main) trace north of Frick Lake was known to be active after the earthquakes. The existence of an east-facing scarp bordering the west side of Frick Lake and the linear extension of that scarp to the south fits the model and is inferred to be the active extension of the Greenville fault south of Frick Lake. However, the only evidence of faulting south of Frick Lake was along the dirt road where 2 mm of right-lateral offset was noted along a small set of left-stepping cracks. Although this trace was not walked-out, no clear evidence of faulting could be identified to the south along Altamont Road.

Stop 4. Laughlin Road at house with broken chimney. Following the January 24 earthquake, extension cracks progressively opened along the road pavement for more than 100 meters. The fact that these cracks trend northwest suggests that they are related to faulting rather than to shaking, which should have caused the cracks to form perpendicular to the road. The existence of tonal lineations and a low northeast-facing scarp on low-sun angle aerial photos (see map) indicates the existence of a zone of recent northwest-trending faults coincidental with the zone of cracking. However, neither vertical nor horizontal slip was measured on any of the cracks. A 1975 exploratory trench of the USGS confirms the existence of a very late Quaternary fault along a low scarp to the southeast (see trench log, Figure 3). The B soil horizon, which shows no evidence of vertical offset, was estimated to be at least 40,000 years old (D. Herd, p.c., 1980). Even so, minor fractures in the B horizon hinted at more recent (minor?) faulting. Perhaps the cracks in the road can be explained by small-scale, distributive slip along the underlying faults. No evidence of faulting associated with the January earthquakes was reported to the southeast of here.

Stop 5. (Optional; hazardous road; narrow shoulders). Narrow-crack zone in Vasco Road reportedly developed during the January 24 earthquakes by a deputy sheriff driving north along the road. Right-slip of nearly 2 cm and vertical slip of 2-4 cm down to the SW were observed 4 hours after the earthquake. The fault rupture was traced as a zone of discontinuous cracks - locally left-stepping - 0.4 km to the southeast and at least 1.5 km to the northwest. 200 meters to the southwest another fault displayed about 2 cm of right-slip. The southwest fault could be traced as discontinuous zone of cracks to the northwest only — partly as the result of afterslip. Fault rupture could not be traced to the southeast. Based on aerial photo interpretation, the southwest fault appears to connect with the main fault on Laughlin Road (Stop 2), but this was not demonstrated by continuous surface rupture. Also, surface rupture was not identified in the epicentral area of the January 24 earthquake 5 to 10 km to the northwest. The fault in the epicentral area was mapped by Colburn (1961) as the Mt. Diablo fault.

Stop 6. (Optional; busy road). Minor northeast-trending cracks were noted in Tesla Road after the 01/24/80 earthquake, 0.3 km west of Mines Road along a trace of the Las Positas fault (Herd, 1977). No slip was measured along these cracks, but their northeast trend oblique to the road suggests possible minor faulting or settlement across a northeast trending structure. Recent measurement of an alignment survey, along South Vasco (Las Positas) 1 km to the east, indicates 2 mm of left slip along the Las Positas fault (Herd, p.c., 4/2/80; this will be documented in Bonilla, et al, 1980). The January 24 earthquake did extensive shaking damage to the nearby Wente Bros. Winery (wine tanks), Lawrence Livermore Laboratories, and Sunset Mobile Home Park.

Figure 4. En echelon fracture patterns diagnostic of right-lateral and left-lateral fault slip:

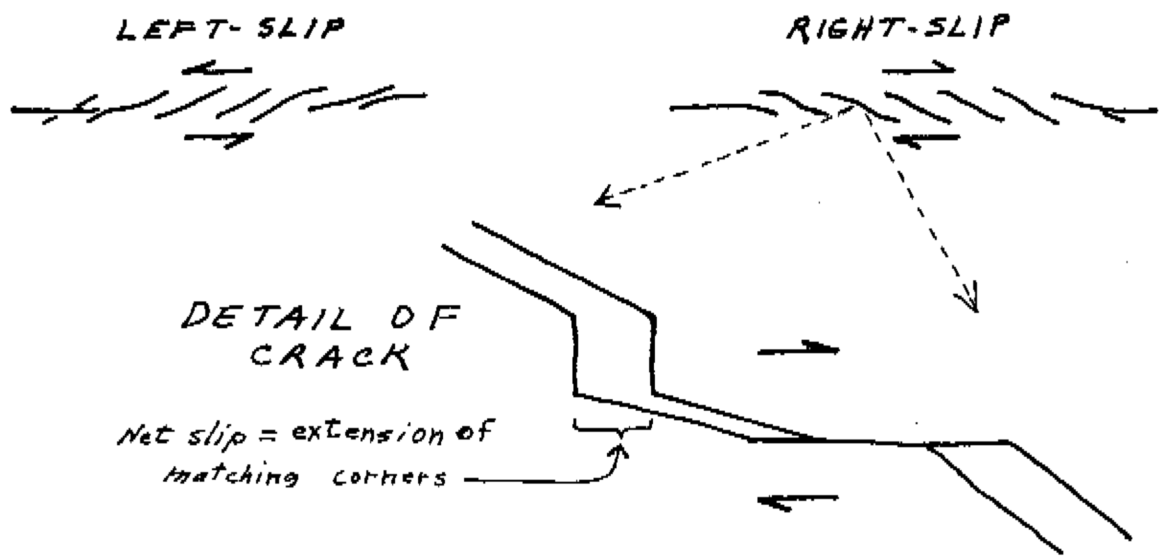


Figure 2. Model for extensional opening and basin formation resulting from right-lateral slip on right-stepping faults.

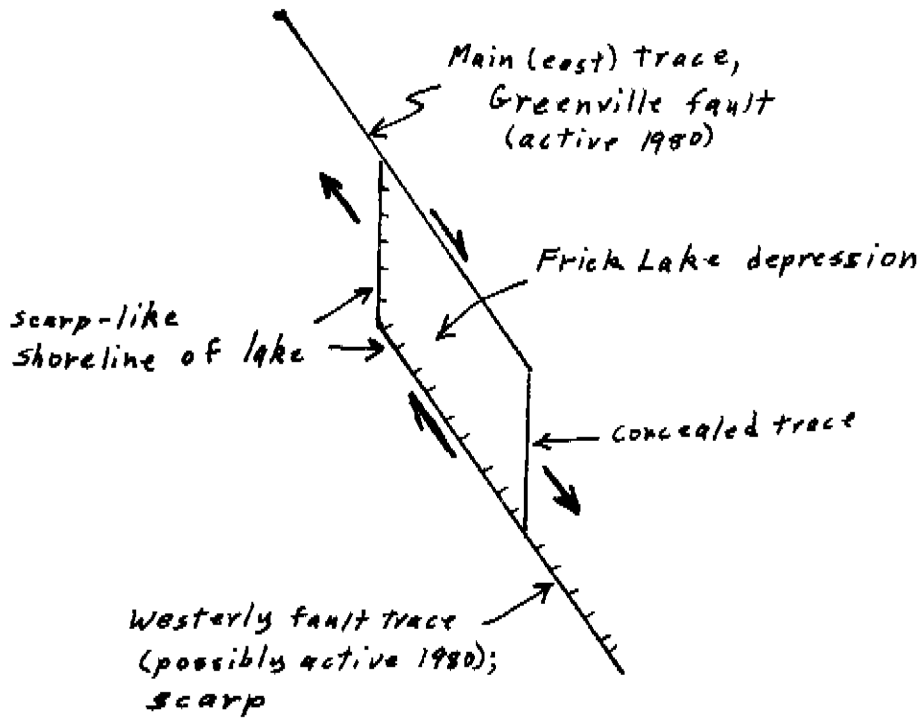
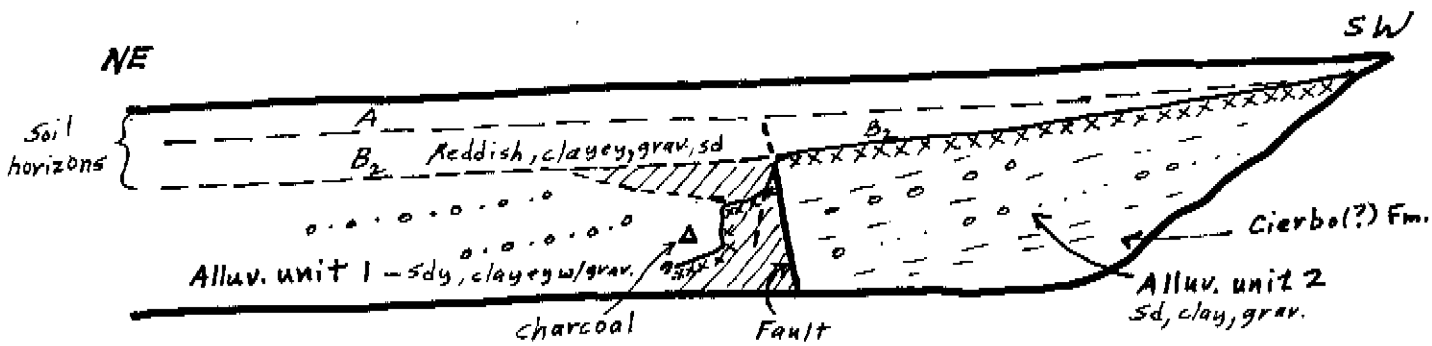


Figure 3. Log of trench excavated across trace of Greenville fault east of Laughlin Road (see Fig. 1) by USGS, 1975.

Sketch of Southeast Wall
by E. Hart, 8/13/75



////// Detrital(?), patchy caliche in gravelly units

xxxxx Pedogenic caliche (in place)

Unit 1 — Late Pleistocene (>40,000 years based on development of B_2 soil horizon (Qoa2 unit of Herd, 1977)

Unit 2 — Late (?) Pleistocene alluvium (>40,000 years)

Scale
0 — 10 ft
Horizontal & vertical

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SURFACE DEFORMATION AND AFTERSLIP ASSOCIATED WITH THE LIVERMORE VALLEY, CALIFORNIA, EARTHQUAKES OF 24 AND 26 JANUARY, 1980

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Coseismic surface rupture was observed along the Greenville fault following earthquakes on 24 Jan. (M5.5) and 26 Jan. (M5.2, USGS; M5.8, U.C. Berkeley). Well-defined first event deformation occurred 8 km southeast of the instrumental epicenter along a 6.5-km-long zone containing two, and possibly five, surface traces. Rupture was continuous in the northern 1.4 km of this zone where approximately 3 cm of right slip was measured across two fault traces in Tertiary sandstone terrane; the southern 5.1 km contained discontinuous en echelon cracks, plus cracks of problematic origin in asphalt pavement, developed mainly in Quaternary alluvium. Second event deformation was concentrated in the southern portion of the zone; existing individual cracks lengthened and widened, numerous new cracks appeared in pavement, and the northern rupture extended .5 km to the south.

Monitoring of ground cracks through 27 Feb. indicates afterslip on fault traces in both bedrock and alluvium. Right slip on a prominent fault trace in alluvium was perceptable on 30 Jan., increased to 2 mm (5 Feb.), 4 mm (10 Feb.), and 7 mm (27 Feb.). Monitoring is continuing.

Ground cracks observed on the conjugate Las Positas fault prior to the second event have increased in number and length through 27 Feb., suggesting concurrent slip during the first event and continuing strain release along this fault.

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Figure 1

PRELIMINARY MAP OF THE GREENVILLE FAULT, NORTHEAST LIVERMORE VALLEY, CALIFORNIA

by

E.W. Hart and T.L. Bedrossian

Data compiled for California Division of Mines and Geology, 3/24/80

EXPLANATION

Linear zone of cracks, formed after January, 1980 earthquakes; dashed where discontinuous; sense of offset identified by RL = right-lateral, V = vertical, E = extension.

Traces of potentially active faults based on interpretation of aerial photos of USGS (1974) and USDA (1940); hachures indicate scarp orientation; linear features identified by symbols:

- bd - beheaded drainage
- cd - closed depression
- dd - deflected drainage (right-lateral sense)
- ld - linear drainage and linear saddle
- pa - ponded alluvium
- t - tonal lines and contrasts due to soil, water, vegetation